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KEY WORDS AND PHRASES

JEMRMS, Space Robotics,
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INTRODUCTION

National Space Development Agency of Japan (NASDA) is developing the Japanese Experiment Module (JEM), as its contribution to the International Space Station. The JEM consists of the pressurized module (PM), the exposed facility (EF), the experiment logistics module pressurized section (ELM-PS), the experiment logistics module exposed section (ELM-ES) and the Remote Manipulator System (RMS), as shown in Figure 1. The JEMRMS services for the JEM EF, which is a space experiment platform.

The JEMRMS consists of the Main Arm (MA), the Small Fine Arm (SFA) and the RMS console.[1] The MA handles the JEM EF payloads, the SFA and the JEM element, such as ELM-ES. The MA consists of three booms, six joints, a base, an end effector, and two vision equipments, as shown in Figure 2. The two long booms are made of Carbon Fiber Reinforced Plastic (CFRP) Tubes, because CFRP has the low thermal expansion, high stiffness and light-weight characteristics. The short boom is an aluminum tube. The six

joints consists of two shoulder joints, one elbow joint, and three wrist joints. Each joint has a brake, which is active without electrical power. Each joint includes the joint electronics unit (JEU), which controls the angle and angular velocity of joint. The base, which consists of titanium, has a curvic coupling to separate the MA from the JEM PM by an EVA crew for maintenance. The end effector is similar to the Standard End Effector of the Space Shuttle. The vision equipment consists of the TV camera and the pan/tilt unit. Only the wrist vision equipment has the arm light. The performance of the MA is Shown in Table 1.

The SFA, which is hold on the tip of the MA during operation, is for dexterous tasks such as the replacement of EF ORUs. The SFA consists of two aluminum booms, six joints, an electronics unit, an end effector, a force/moment sensor and a TV camera. The six joints consists of two shoulder joints, one elbow joint, and three wrist joints. Each joint has a brake, which is active without electrical power. The electronics unit controls the angular velocity of the six joints. The end effector, which is called the tool, grasps the tool fixture and supplies the torque to the bolt. The performance of the

SFA is shown in Table 1.

The MA and the SFA are operated from the RMS console by a crew in the JEM PM. The RMS console consists of two TV monitors, passive rotation and translation hand controllers (RHC/THC), a hand controller electronics (HCEL), a remote interface panel (RIP), a laptop workstation (LTWS), a task light, a management data processor (MDP), a mass storage unit (MSU), an arm control unit (ACU), a power distribution box, a rack essential package (REP), a fire detection and suppression (FDS) panel, a hold and release mechanism electronics and a standard double size rack. One split screen capability is provided by NASA, a crew can use three video views simultaneously for the robotics operation. Due to the redesign of the space station, especially termination of the multi-purpose application console (MPAC), we are redesigning the RMS console. The concept design review will be held at the end of October, 1994.

The JEMRMS is currently in the critical design phase. The summary of design, analysis and verification plan of the MA, especially including dynamics and control, is presented.

DYNAMICS

The eigenvalue of the MA is calculated by the Finite Element Model (FEM) in both orbit and launch configurations, as shown in Table 2. The reference configuration is near extended configuration except elbow pitch joint, whose angle is 150 degree to avoid the singularity. The storage configuration is selected to reduce a heater power and to have higher natural frequency than one in the reference configuration. The natural frequencies in orbit configuration are mainly determined by the torsional stiffness of the joint, which is mainly determined by the torsional stiffness of the speed reducer. The

current value of the torsional stiffness is derived from the result of the BBM joint test.

In launch configuration, the MA is stowed on the aft end plate of the JEM PM by three hold and release mechanisms (HRM). Before deployment on orbit, the forced relative displacement by the JEM PM deformation due to its pressure is induced large loads in the MA. The load relief in the boom axial direction is installed in the one of HRMs.[2]

CONTROL

The angle and angular velocity of each joint of the MA is controlled by each JEU as shown in Figure 3. The MA is operated in preprogrammed control (primary) and manual control with RHC/THC. For the SFA, the manual control is primary. The controller is designed for not the output axis of the speed reducer but the motor axis to omit the joint backlash in the closed loop. The eight sets of control parameters, which are stored in each JEU, are selected by the ACU depending upon the payload mass property and the arm configuration. The performance of the MA is determined by each joint characteristics, the extensive dynamic analysis with the controller is performed by the non-real time computer simulator.[3] The example of the result, the position error (relative to arm base) in handling the 2300 Kg payload in the preprogrammed control, is shown in Figure 4. The analytical error is smaller than the requirement in Table 1, finally the mathematical model will be updated by the function test using the flat floor.

To maintain the positioning accuracy (relative to target) for misalignments of the JEM due to assembly and thermal distortion, position and orientation of a target can be measured by the wrist vision

equipment and the MDP in preprogrammed control.[1]

VERIFICATION

The tests, as shown in Table 3, are planned for the engineering model (EM) of the MA from the summer in 1995 to the summer in 1996. The function test is including the two dimensional flat floor test. The mathematical model of the MA in orbit and launch configuration will be updated by the result of the modal survey and the function test with the flat floor. The static load test and the random vibration are qualification test.

In the end-to-end system test with the MA, the RMS console and the SFA, only the extensive function test including the two dimensional flat floor test of the MA with the SFA is planned.

CONCLUDING REMARKS

The summary of design, analysis and verification plan is presented. The EM of the MA will be manufactured by the spring in 1995. The performance of the MA will be verified by the test successfully.

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Table 1. Performance of JEMRMS.

Items	MA	SFA
Maximum payload mass Kg	7000	300
Maximum tip velocity		
Translation mm/sec	20 ¹	10 ²
mm/sec	30 ³	30 ⁴
mm/sec	60 ⁵	
Rotation deg/sec	0.5 ¹	0.5 ²
deg/sec	1.0 ³	1.0 ⁴
deg/sec	2.5 ⁵	
Maximum Tip force N	30	30
Positioning accuracy		
<Relative to arm base>		
Translation mm	+50	+10
Rotation deg	+1.0	+1.0
<Relative to target>		
Translation mm	+50	+10
Maximum stopping distance		
Translation mm	300	75
Rotation deg	5	5

Note:

- 1 : less than 7000 Kg payload
- 2 : less than 300 Kg payload
- 3 : less than 3000 Kg payload
- 4 : less than 130 Kg payload
- 5 : less than 600 Kg payload

Table 2. Eigenvalues of the MA.

Items	Natural Frequency[Hz]	
	1st	2nd
On orbit		
<Reference Config.>		
No payload	0.32	0.34
Payload(500Kg)	0.19	0.21
Payload(7000Kg)	0.046	0.05
<Storage Config.>		
No payload	0.65	1.01
Launch	14.2	14.9

Table 3. Tests for the MA in EM Phase

Function test
Modal survey(Orbit & Launch)
Static load test
Random vibration test(TBD)
EMC
Thermal balance test

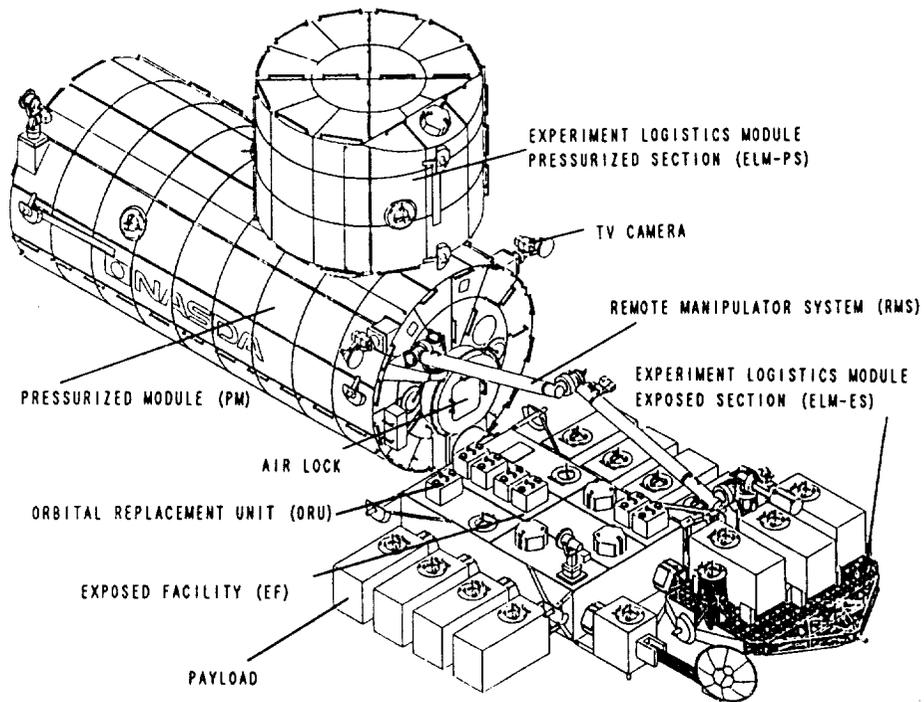


Figure 1. JEM configuration.

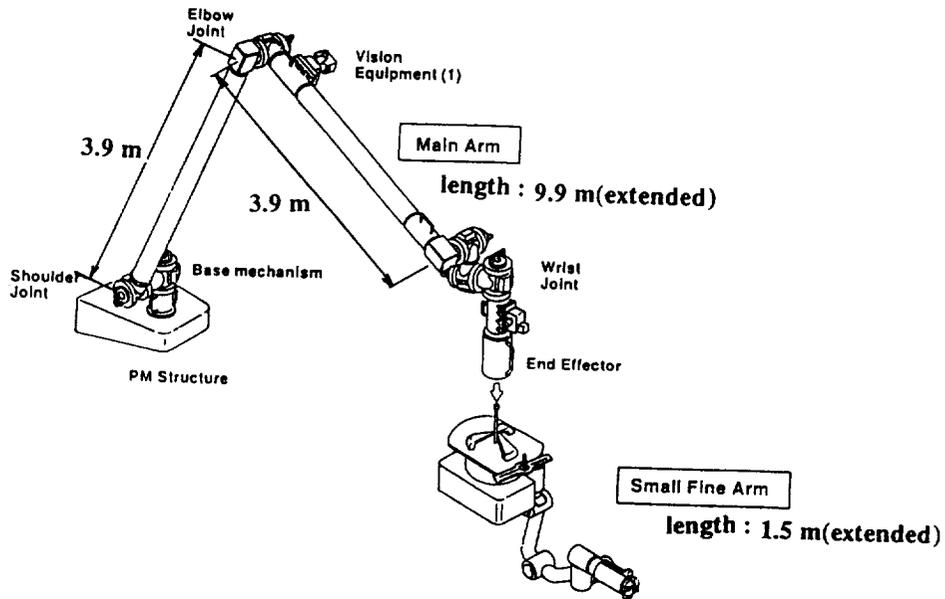


Figure 2. JEMRMS arm configuration.

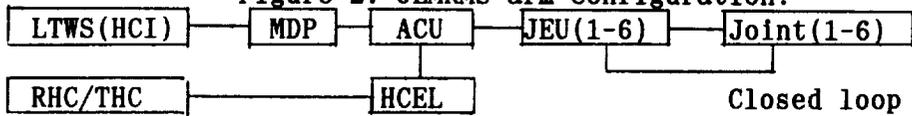


Figure 3. Control diagram of the MA.

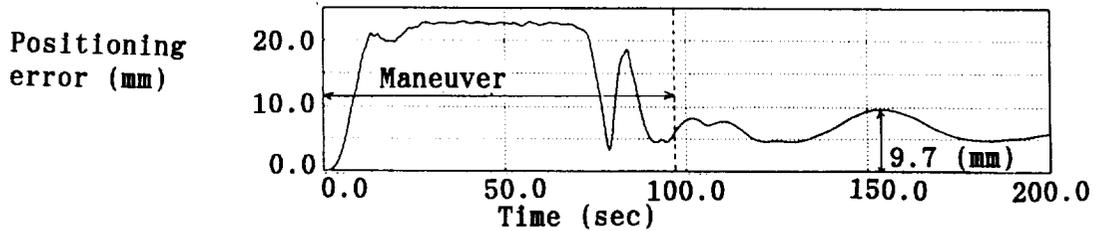


Figure 4. Position error in handling the 2300 Kg payload.